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HIGH T_C SUPERCONDUCTOR/ FERROELECTRIC HETEROSTRUCTURES

SRI International

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Thin films of the ferroelectric perovskite, $Ba_xSr_{1-x}TiO_3$(BST), were deposited on superconducting (100)$YBa_2Cu_3O_x$(YBCO)/(100)Yttria-stabilized (YSZ) substrates and (100)Si by ion-beam sputtering. Microstructural and compositional features of the ceramic bilayer were assessed by a combination of x-ray diffraction (XRD) and scanning electron microscopy. The films were smooth and featureless, and energy dispersive x-ray spectroscopy (EDX) data indicated that film composition closely matched target composition. XRD analysis showed that films deposited on YBCO substrates were highly c-axis textured, while the films deposited on (100)Si did not exhibit any preferred growth morphology. The superconducting properties of the YBCO substrate layer were maintained throughout the processing stages and, as such, it was demonstrated that ion beam sputtering is a viable method for the deposition of Ferroelectric/YBCO heterostructures.

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ABSTRACT

Thin films of the ferroelectric perovskite, $Ba_xSr_{1-x}TiO_3$ (BST), were deposited on superconducting (100) $YBa_2Cu_3O_x$ (YBCO) / (100) Yttria-stabilized zirconia (YSZ) substrates and (100) Si by ion-beam sputtering. Microstructural and compositional features of the ceramic bilayer were assessed by a combination of x-ray diffraction (XRD) and scanning electron microscopy. The films were smooth and featureless, and energy dispersive x-ray spectroscopy (EDX) data indicated that film composition closely matched target composition. XRD analysis showed that films deposited on YBCO substrates to be highly c-axis textured, while the films deposited on (100) Si did not exhibit any preferred growth morphology. The superconducting properties of the YBCO substrate layer were maintained throughout the processing stages, and as such, it was demonstrated that ion beam sputtering is a viable method for the deposition of Ferroelectric/YBCO heterostructures.

INTRODUCTION

The research on thin film ferroelectric materials has been primarily driven, in recent times, by the development of the non-volatile ferroelectric random access memory (FRAM) device, and the reader is referred to the Reference literature list (particularly, the work of Ramesh *et.al.*) for details. In general, and similar to other applications of electronic ceramic thin films, the performance of FRAM devices is highly influenced by the crystalline quality of the ferrolectric film and the characteristics of the film-electrode interface. By utilizing a substrate (i.e., bottom electrode) which is both lattice and chemically matched, it should be possible to induce epitaxial growth of the ferroelectric layer and thus minimize defect structures associated with grain boundary effects. The perovskite ferroelectrics (e.g., $(Ba,Sr)TiO_3$, $Pb(Zr,Ti)O_3$, etc.) and the perovskite YBCO superconductor possess similar lattice structure (i.e., 2-3% lattice match in the *a-b* plane) and crystal chemistry and thus provide an ideal system from which to base an experimental program. While the work of Ramesh *et.al.* at Bellcore has demonstrated that important ferroelectric performance properties (i.e., fatigue and ageing) of pulsed laser-deposited $Pb(Zr,Ti)O_3$ were improved when the films were grown heteroepitaxially on YBCO, they did not comment on the superconducting properties of the YBCO electrode. An objective of this work was to investigate how the superconducting properties of the YBCO layer was effected by the deposition processing of the BST layer.

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EXPERIMENTAL

Thin Film Processing

$Ba_xSr_{1-x}TiO_3$ (x = 0.25, 0.75) films were ion beam sputter deposited from stoichiometric ceramic oxide targets. A 3 cm Kaufman source (Commonwealth Scientific, Inc.) was utilized to generate the Ar^+ ion sputter beam which was positioned at an incident angle of 45° to the target. A low energy, gridless ion source (Commmonwealth Scientific, Inc.), which was directed at the substrate with an incident angle of 45°, was utilized to preclean (by Ar^+ ion sputtering) the substrates prior to film deposition. A gas dispersion ring located near the substrate was used to introduce oxygen during deposition. Films were deposited at a total pressure of 2.0×10^{-4} torr (1.0×10^{-4} torr Ar and 1.0×10^{-4} torr O_2). Substrate temperature was varied within the range of 550 to 650 °C over the course of this study. Deposition rate was on the order of 0.3 to 0.6 nm/min., and final film thickness was on the order of 200 to 250 nm as measured by surface profilometry.

The YBCO/YSZ substrates were commercially obtained (Excel Superconductor, Bohemia, NY) and were used as is. The silicon substrates were briefly etched in 10% aqueous HF and rinsed in distilled, deionized H_2O prior to entry to the vacuum system. Given that the principal study related to film deposition on YBCO and that the Si substrate depositions were only done for comparison purposes, it is noted that the film deposition conditions would in all likelihood result in the formation of an SiO_2 layer on the Si which would negatively impact the quality of the BST/Si film samples. Prior to film deposition, the substrates were heated to the deposition temperature and sputter cleaned (i.e., removal of approximately a 10 nm surface layer) by a low-energy Ar^+ ion beam.

RESULTS and DISCUSSION

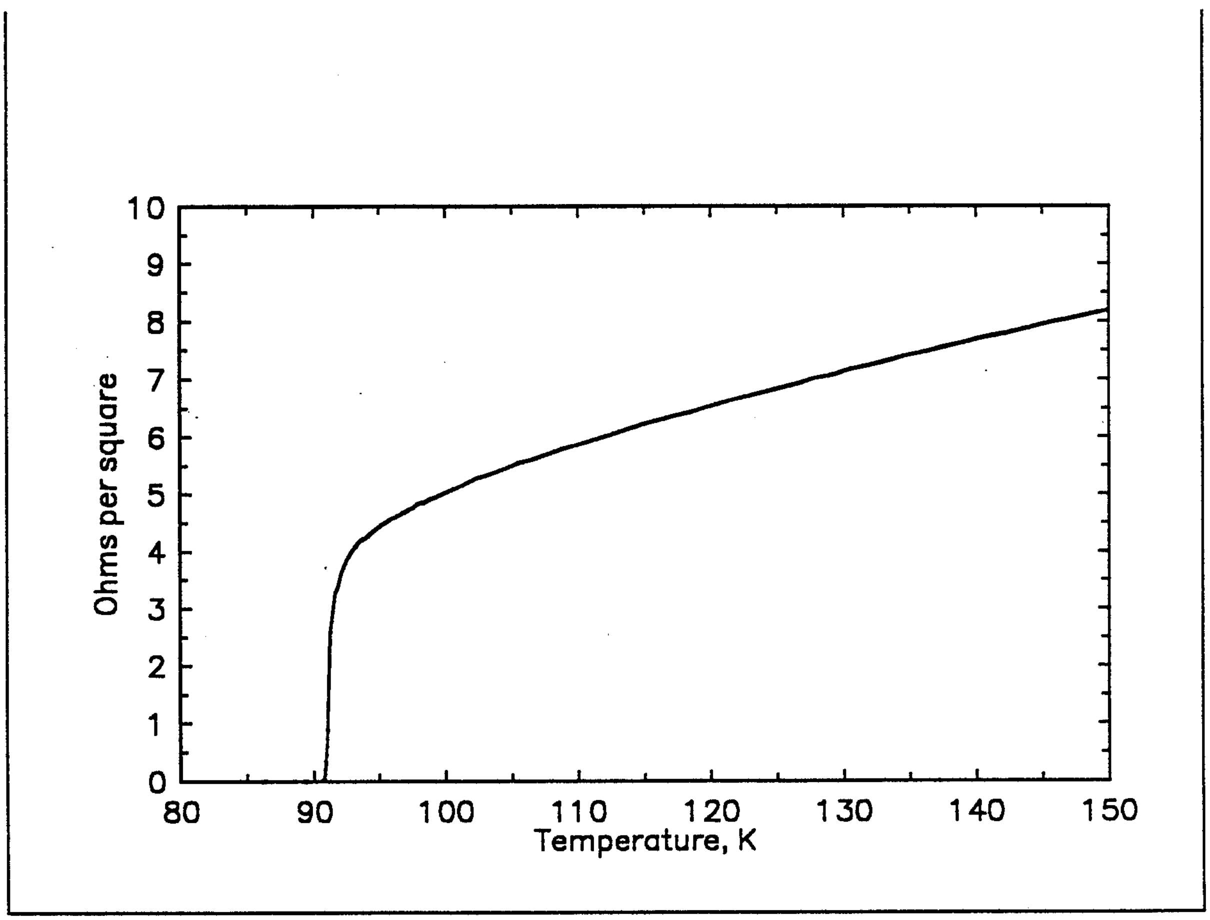
BST films deposited *in situ* at a substrate temperature of approximately 650 °C were visually observed to be smooth and optically reflective. Electrical measurements showed that the resistivity of the crystalline BST films ranged from 10^4 to 10^8 Ω-cm, with the more resistive films associated with higher deposition temperatures. Bulk sample data reported in the literature indicate a resistivity on the order of 10^9 to 10^{10} Ω-cm and as such, it is presumed that low level impurities (not detected by EDX measurements) and/or defect structures (i.e., oxygen vacancies) reduced film resistivities. Due to the high leakage current of the deposited films, the ferrolelctric properties of a test Pt/BST/YBCO capacitor structure could not be analyzed.

XRD analysis indicated that films deposited on (100) YBCO were highly c-axis oriented, while films deposited on (100) Si did not exhibit any preferred orientation effect. This is

consistent with our previous results relating to the sol-gel processing of $Pb(Zr,Ti)O_3$ films on (100) YBCO and Pt-coated Si, but the microstructural quality of the sputtered films were superior to that of the sol-gel-derived films.

The superconducting properties of the YBCO base layer were determined by the DC four probe method both prior and after deposition of the BST overlayer. Figure 1 shows that *in situ* BST film processing had minimal effect on the electrical properties of the YBCO layer as a

Figure 1



sharply-defined T_c of approximately 90 K is maintained.

CONCLUSIONS

$Ba_xSr_{1-x}TiO_3$ (x=0.25, 0.75) films were deposited *in situ* on (100) YBCO/YSZ substrates by ion beam sputtering. Based on EDX results, and substantiated by the analysis of XRD data, the composition of a deposited film was consistent with the stoichiometry of the single oxide target utilized. XRD analysis showed that films deposited on "lattice-matched" YBCO substrates to be highly c-axis textured, while films deposited at the same growth conditions on (100) Si did not exhibit any preferred crystallographic orientation. The resistivity of the ion-beam sputtered BST films were lower that bulk reported values and is probably related to low level impurities and/or oxygen defects. The superconducting properties of the YBCO base layer were not effected by the BST deposition process, and as such ion beam sputtering affords a viable method for the fabrication of Ferroelectric/Superconductor -based device structures.

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